Sequence Containers

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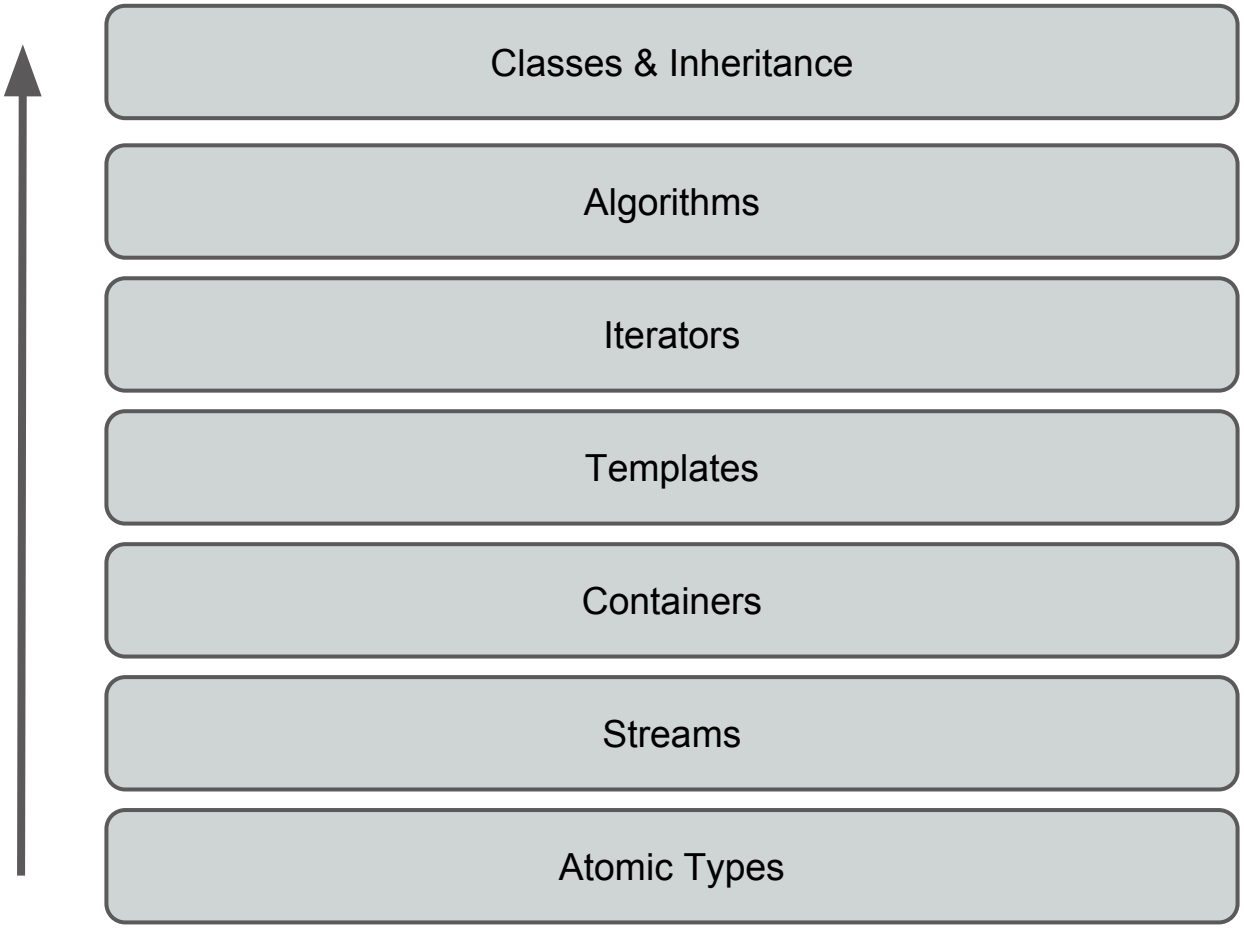
The Design of C++



Structs

- A struct is an easy way to bundle multiple variables together
- We will cover them more in depth later but you may find them useful for the first assignment

Structs

```
struct point {
   int x;
   int y;
};

point p;
p.x = 4;
p.y = 3;
```

Administrivia

- Assignment one is officially out today!
- Due date Tuesday, October 13th at 11:59 pm

Administrivia

- LaIR help available:
  - TBA (will email)
- Email help available
  - ccibils@stanford.edu

STL

STL

- Stands for Standard Template Library
- In it we can find all the nifty tools C++ puts at our command
- (Most of the stuff in the design of C++ is extremely influenced by the existence of the STL)

Review: Sequence Containers

- A container class allows you to store any number of (any type of) things
- A sequence container is a container whose elements can be accessed sequentially.
- Sequence containers include vectors, stacks, queues, lists, and priority queues (and many more!).

What I Want To Show You

- Why the Stanford library exists
- How to use STL sequence containers instead of the Stanford Library
  - We'll look at the differences between STL/Stanford using stack and vector, and we'll also examine a new STL class, deque
- Performance of different containers, and why you might choose one over another

Why the Stanford Library Exists

Students often ask:

"Why do we need to use the Stanford libraries in CS106B/X?"

Why the Stanford Library Exists

- The Stanford libraries include things not found in the STL (`Grid`, `getInteger` and friends, graphics).
- Many parts of the Stanford library give up performance for simplicity
- Debugging Stanford library code can be much easier than debugging STL code

Container #1: Stack

First, let's talk about how
to use the STL stack.

STL <stack>: What's Similar

What you want to do	Stanford Stack<int>	STL stack<int>
Create a stack	`Stack<int> x;`	`stack<int> x;`
Get the size of a stack	`int size = x.size();`	`int size = x.size();`
Check if a stack is empty	`if (x.isEmpty()) ...`	`if (x.empty()) ...`
Push a value on the stack	`x.push(42);`	`x.push(42);`
Peek at the top element without popping it	`int top = x.peek();`	`int top = x.top();`
Pop off the top element and ignore its value	`x.pop();`	`x.pop();`

STL <stack>: What's Different

What you want to do	Stanford Stack<int>	STL stack<int>
Clear the stack	`x.clear();`	`while(!x.empty())` `  x.pop();`

Convert the stack to a string	`string s = x.`
	`toString();`
		`string s;`
		`while(!x.empty() {`
		`  s += x.top();`
		`  s += " ";`
		`  x.pop();`
		`}`

Pop and save the value	`int top = x.pop();`	`int top = x.top();` `x.pop();`

STL <stack>: Usage

Let's look at a quick demo in `STLStack.pro`

STL <stack>: Why the differences?

Looking at the differences between the STL and the Stanford libraries can help you understand the the reason each of these libraries were designed.

“Thus, the standard library will serve as both a tool and as a teacher”

- Bjarne Stroustrup

STL <stack>: Why the differences?

Why is there no .clear() function for stacks?

STL <stack>: Why the differences?

Why is there no .clear() function for stacks?

- Conceptually, clearing isn't part of the interface to a stack
- It's very easy to write your own clear function:

```
// stack<int> s = ...;
while (!s.empty()) {
  s.pop();
}
```

STL <stack>: Why the differences?

Why doesn't pop return the value it removed?

STL <stack>: Why the differences?

Why doesn't pop return the value it removed?

- The caller might not need the value, in which case returning the value would be wasteful.
- It's easy to write code which pops and saves the value.

```
// stack<int> s = ...;
int value = s.top();
s.pop();
```

STL <stack>: Why the differences?

Why isn't there a `toString` function?

STL <stack>: Why the differences?

Why isn't there a `toString` function?

- Implementing toString would require that the type stored in the stack could be converted to a string
  - For example, you can convert a `stack<int>` to a `string` because you can convert an `int` to a `string`.
- It's tough to say what the "proper" way to convert a stack to a string is

Container #2: Vector

First, let's talk about how vectors are represented in the STL.

STL <vector>: What's Similar

What you want to do	Stanford Vector<int>	STL vector<int>
Create an empty vector	`Vector<int> v;`	`vector<int> v;`
Create a vector with n copies of zero	`Vector<int> v(n);`	`vector<int> v(n);`
Create a vector with n copies of a value k	`Vector<int> v(n, k);`	`vector<int> v(n, k);`
Add a value k to the end of the vector	`v.add(k);`	`v.push_back(k);`
Clear a vector	`v.clear();`	`v.clear();`
Get the element at index i (verify that i is in bounds)	`int k = v.get(i);` `int k = v[i];`	`int k = v.at(i);`
Check if the vector is empty	`if (v.isEmpty()) ...`	`if (v.empty()) ...`
Replace the element at index i (verify that i is in bounds)	`v.get(i) = k;` `v[i] = k;`	`v.at(i) = k;`

STL <vector>: What's Different

Get the element at index i without bounds checking	`// Impossible!`	`int a = x[i];`
Change the element at index i without bounds checking	`// Impossible!`	`x[i] = v;`
Apply a function to each element in x	`x.mapAll(fn)`	`// We'll talk about this in another lecture...`
Concatenate vectors v1 and v2	`v1 += v2;`	`// We'll talk about this in another lecture...`
Add an element to the beginning of a vector	`// Impossible! (or at least slow)`	`// Impossible! (or at least slow)`

STL <vector>: Usage

Let's look at a quick demo in `STLVector.pro`

STL <vector>: Why the differences?

Why doesn't vector have bounds checking?

STL <vector>: Why the differences?

Why doesn't vector have bounds checking?

- If you write your program correctly, bounds checking will do nothing but make your code run slower

STL <vector>: Why the differences?

Why is there no push_front method?

STL <vector>: Why the differences?

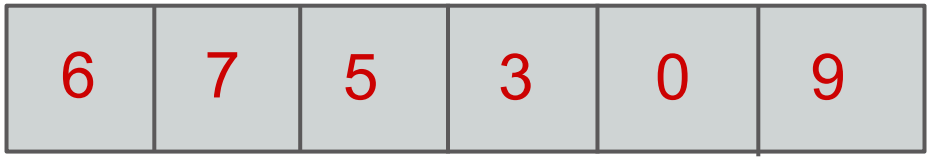
Why is there no push_front method?

- This is a bit more complicated

The Mystery of `push_front`

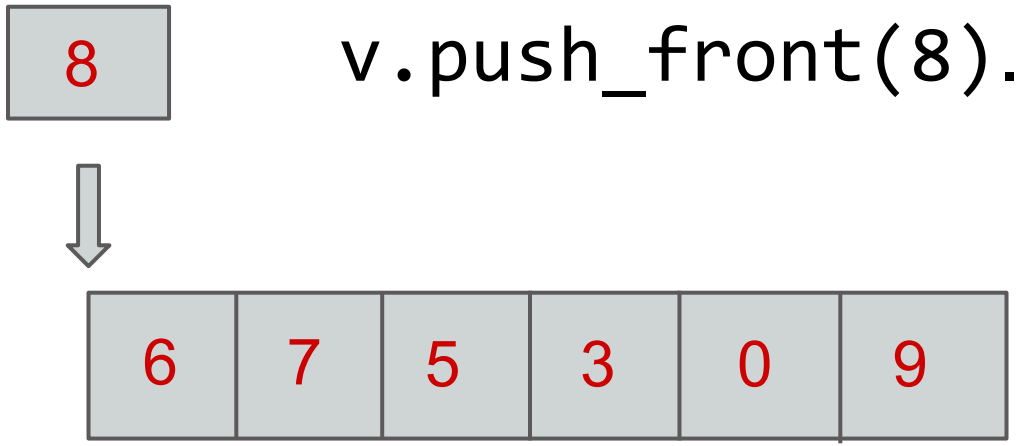
Pushing an element to the front of the vector requires shifting all other elements in the vector down by one, which can be **very** slow

To demonstrate this, let's say we had this nice little vector:



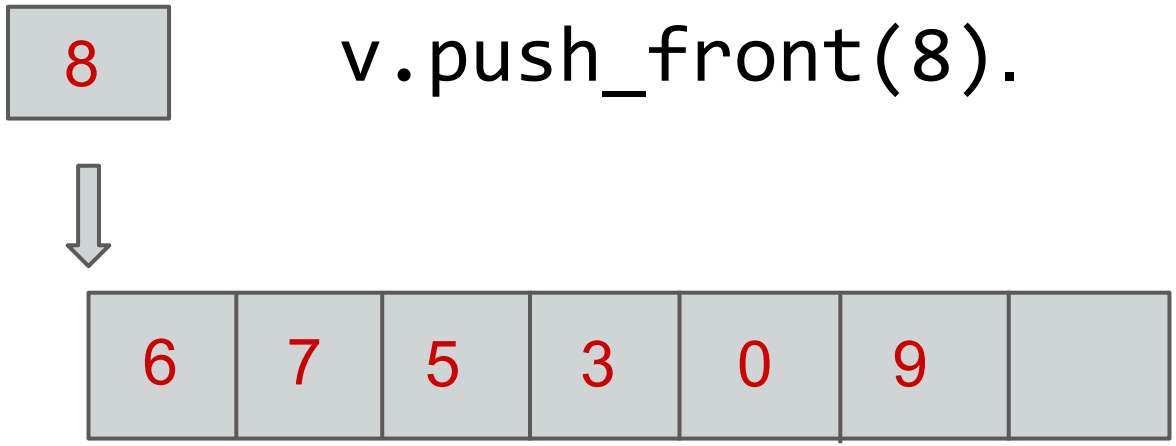
The Mystery of `push_front`

Now, let's say that `push_front` existed, and that you wanted to insert an 8 at the beginning of this vector.



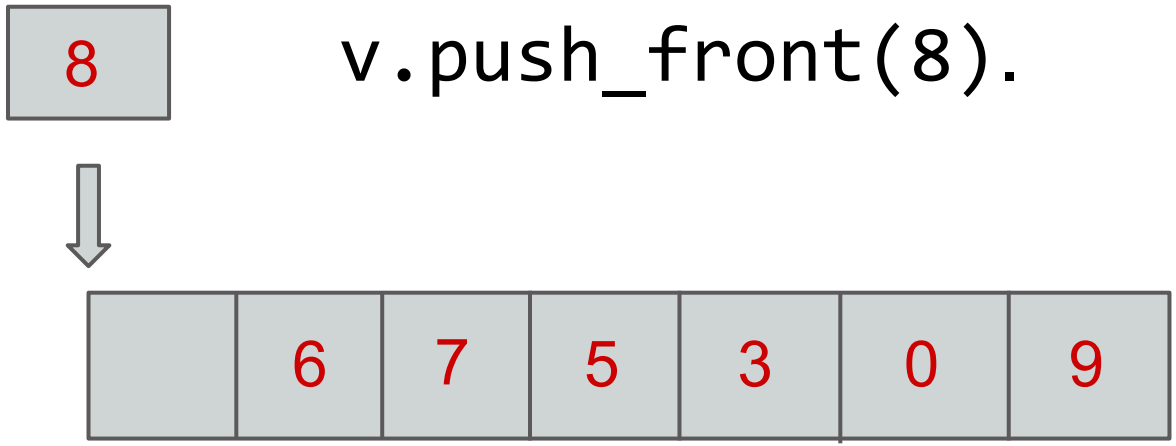
The Mystery of `push_front`

First, we may have to expand the capacity of the vector



The Mystery of `push_front`

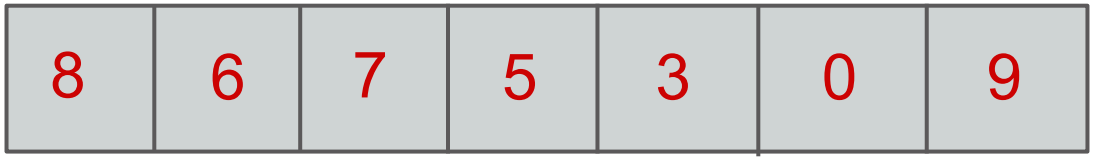
Then, we'll need to shift every single element down one position



The Mystery of `push_front`

Finally, we can actually insert the element we wanted to insert.

```
v.push_front(8).
```



Just how bad is push_front?

```
// Adding to the back
for (int i = 0; i < N; i++)
   v.push_back(i);

// Or: Adding to the front
for (int i = 0; i < N; i++)
   v.insert(v.begin(), i);

// How big can the difference be?
```

Just how bad is push_front?

	`push_front`	`push_back`
N = 1000	0.01	0
N = 10000	0.89	0.01
N = 100000	117.98	0.04
N = 1000000	Hours	0.31
N = 10000000	Years	3.16

You can see the difference between an $O(n^2)$ algorithm and an O(n) algorithm!

STL <deque>: What's a deque?

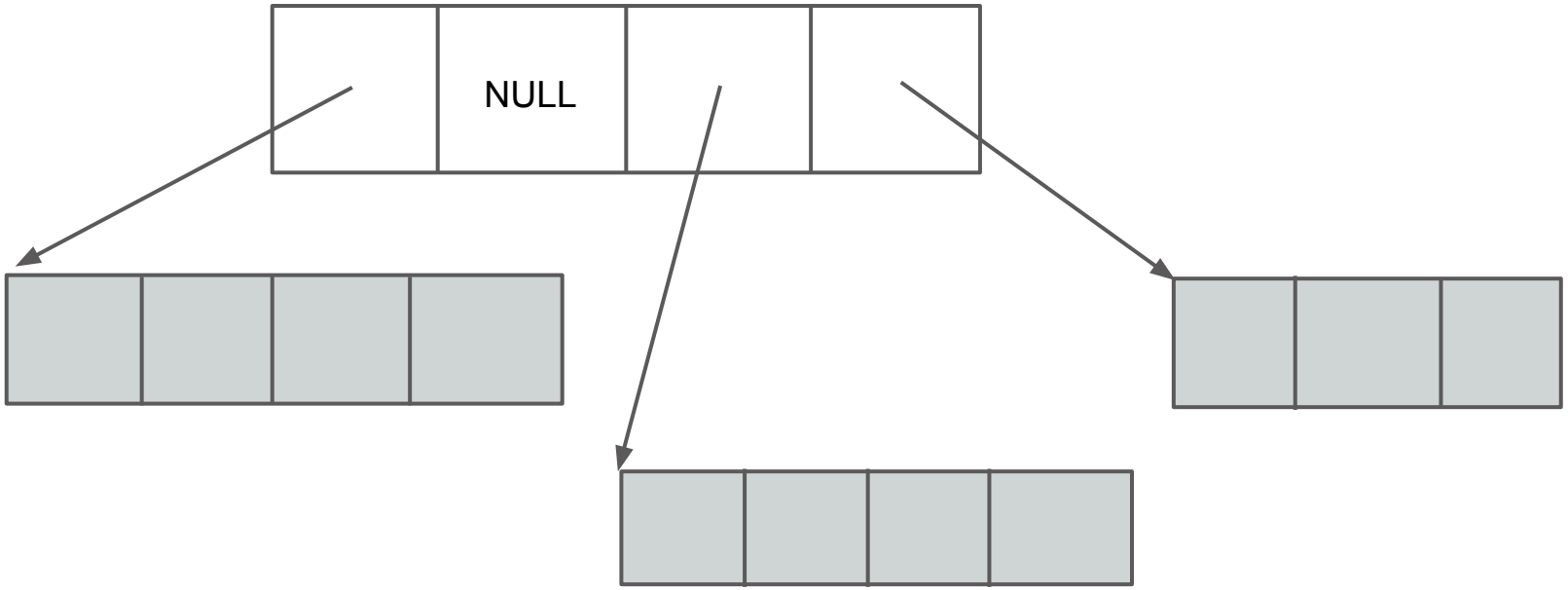
- A deque (pronounced "deck") is a **d**ouble **e**nded **que**ue
- Unlike a vector, it's possible (and fast) to push_front
- The implementation of a deque isn't as straightforward as a vector though

STL <deque>: Usage

Let's look at a quick demo in `STLDeque.cpp`

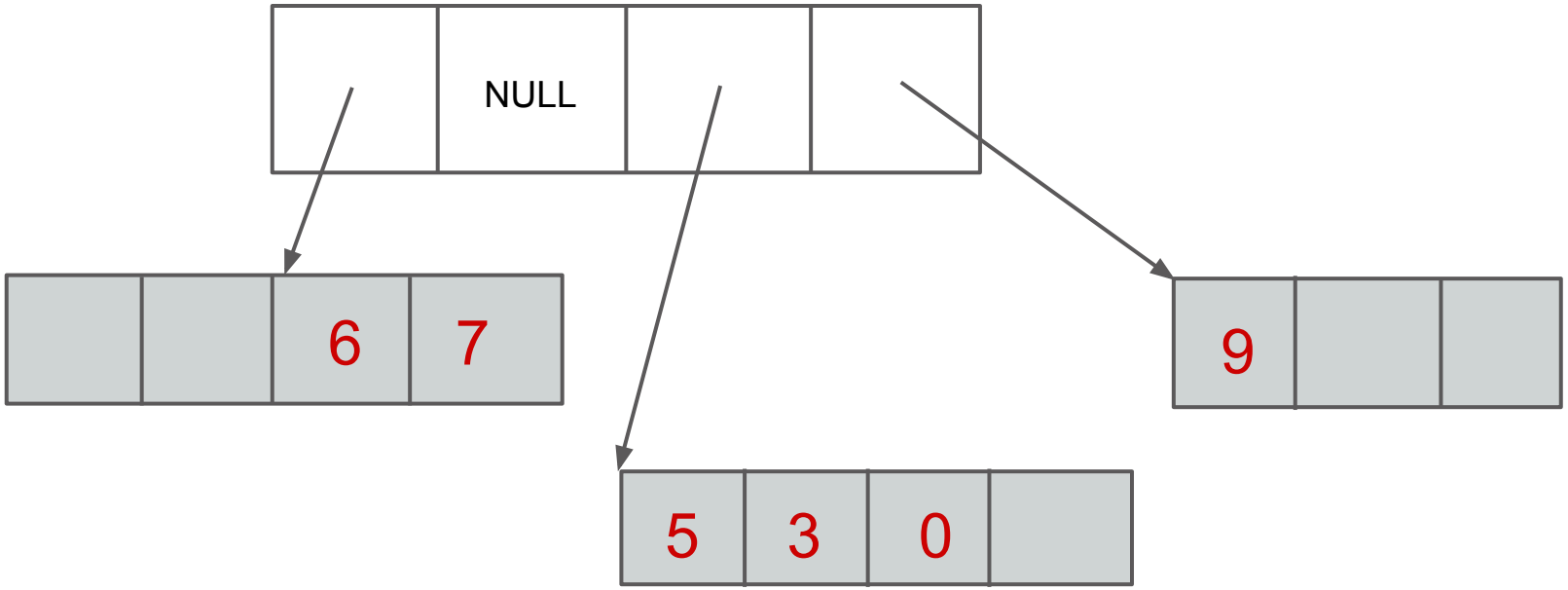
STL <deque>: Implementation

There's no single specification for representing a deque, but it might be laid out something like this



STL <deque>: Implementation

You could support efficient insertion by keeping some reserved space in front of the vector representing the first elements of the deque



STL <deque>: Implementation

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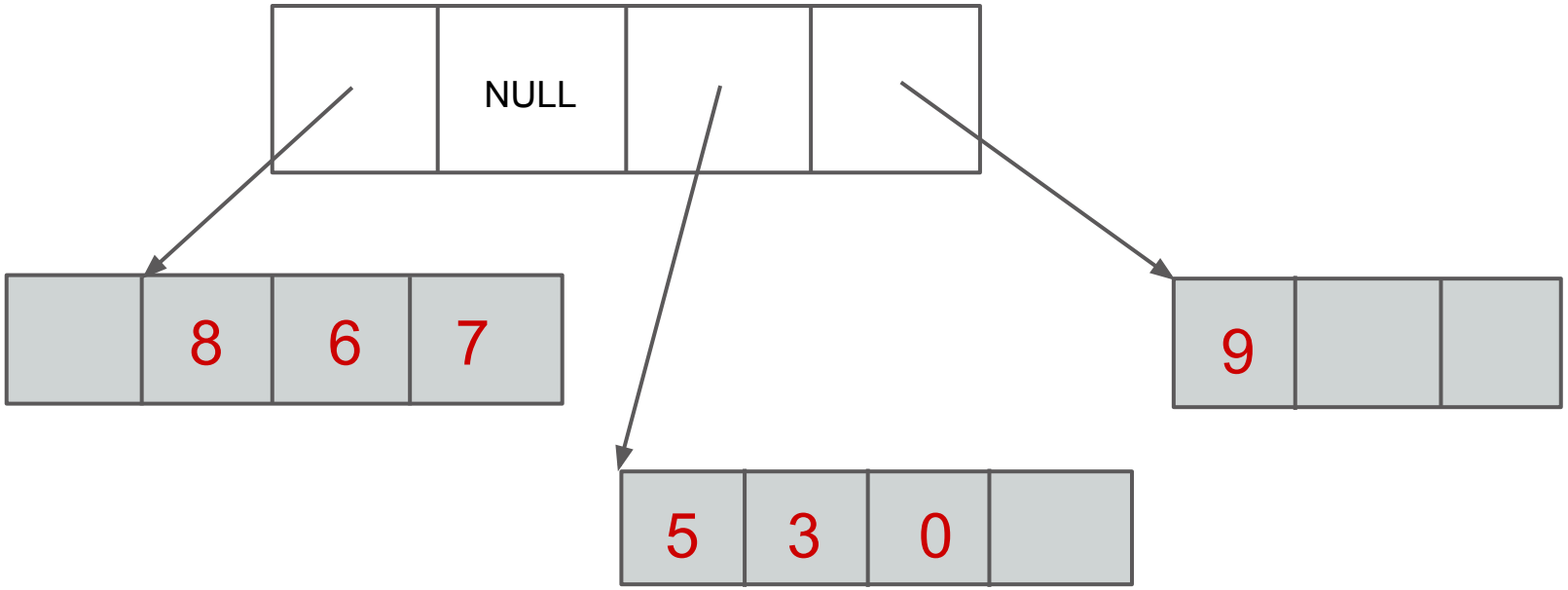

STL <deque>: Performance

- We can now use the `push_front` function, and it will run much faster than if we had used a vector.
- Let's see how this looks in real world performance numbers

push_front: vector and deque

```
// Vector test code
vector<int> v;
// Insert at the start of the vector
for (int i = 0; i < N; i++)
   v.insert(v.begin(), i);
// Clear by using pop_front (erase)
for (int i = 0; i < N; i++)
   v.erase(v.begin());
```

push_front: vector and deque

```
// Deque test code
deque<int> d;
// Insert elements using push_front
for (int i = 0; i < N; i++)
   d.push_front(i);
// Clear by using pop_front
for (int i = 0; i < N; i++)
   d.pop_front();
```

push_front: vector and deque

	<vector>	<deque>
N = 1000	0.02	0
N = 10000	2.12	0.01
N = 100000	264.9	0.04
N = 1000000	Years	0.44
N = 10000000	Millenia	5.54

Why use a vector?

If a deque can do everything a vector can plus add to the beginning, why not always user deques?

Why use a vector?

If a deque can do everything a vector can plus add to the beginning, why not always user deques?

- For other common operations like access and adding to the end, a vector outperforms a deque

Element Access: vector and deque

```
vector<int> v(N);
deque<int> d(N);

for (int i = 0; i < N; i++)
   v[i] = i;

for (int i = 0; i < N; i++)
   d[i] = i;
```

Access: vector and deque

	<vector>	<deque>
N = 1000	0.02	0.14
N = 10000	0.28	1.32
N = 100000	3.02	13.22
N = 1000000	30.84	133.30

push_back: vector and deque

```
// Vector test code
vector<int> v;
// Insert elements using push_back
for (int i = 0; i < N; i++)
   v.push_back(i);
// Clear by using pop_back
for (int i = 0; i < N; i++)
   v.pop_back();
```

push_back: vector and deque

```
// Deque test code
deque<int> d;
// Insert elements using push_back
for (int i = 0; i < N; i++)
   d.push_back(i);
// Clear by using pop_back
for (int i = 0; i < N; i++)
   d.pop_back();
```

push_back: vector and deque

	<vector>	<deque>
N = 1000	0.02	0.02
N = 10000	0.20	0.20
N = 100000	1.98	1.92
N = 1000000	19.9	20.78

Other Sequence Containers

The STL also includes priority queue, queue, and linked list classes, but those aren't too important to us right now.

Next Time

- Associative Containers
- Maps, Sets, and More!